INFLUENCE OF PRECIPITATION AND TEMPERATURE ON RING, ANNUAL BRANCH INCREMENT, AND NEEDLE GROWTH OF WHITE FIR AND DOUGLAS-FIR IN CENTRAL UTAH

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Abstract.— The study evaluates growth variations in mixed stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and White Fir (*Abies concolor* Hoopes) from the Bighorn Ranch in northern Sanpete County, Utah. The study area lies 26 km southwest of Thistle, Utah. Tree-ring width, annual branch growth and needle length for the period 1970–1976 were obtained from Douglas-Fir and White Fir individuals distributed along an altitidinal and moisture gradient. Elevation ranged from 2257 m to 2500 m above sea level.

Temperature and precipitation are shown to exert a significant influence on needle and annual branch growth and width of the annual rings. It was found that multiple correlation coefficients were always larger than the simple correlation coefficients. This suggests that the trees are responding to both temperature and precipitation. Annual branch growth is shown to be positively correlated with ring width and needle length. The influence of precipitation on growth is synchronized with 1 October–1 June precipitation. Best growth occurs in cool, moist years and at lower elevations.

Work on growth variations in conifer trees is not new. The use of ring width as a relative measure of secondary growth has long been studied in the West and Southwest (Douglass 1919, Fritts et al. 1965, Fritts 1966, Tappeiner 1969, Kozlowzki 1971, Drew 1972). The fact that variations in ring width sequences from certain trees may be used to date wood (Douglass 1919) and reconstruct past climates (Fritts 1971, Stokes and Smiley 1968, Arnold 1947, Chaloner and Creber 1973, Seward 1892, Schwarzbach 1971, Antevs 1953) is well established. There is, however, a paucity of research on normal variations in needle retention and length as well as annual branch growth for these conifer trees, although some research has been done (Lamb 1969, Peckham 1973). Such research is needed to detect the effects of low levels of atmospheric contaminants on tree growth. Research has demonstrated that air pollution can induce abnormal, nonclimatic variation in ring width and needle length and retention. Pollutants can depress width of tree-rings (Nash et al. 1967) and needle length and vigor (Anderson 1966, Teshow 1968, Treshow et al. 1967). Although Nash et al. (1975) could not directly link air pollution with decreased ring width, it was strongly implicated. Reduced needle length and vigor have been directly linked to air pollutants of various kinds, as shown by Treshow et al. (1967), Treshow (1968), and Anderson (1966). An extensive bibliography and discussion of air pollution and its affects on trees can be found in Mansfield (1976). The effects of air pollution from fluoride, dust, or sulphur dioxide were considered to be negligible in this study, largely on the basis of the general vigor of Douglas-fir, which is considered to be the most susceptible of all the western trees to the pollutants listed (Anderson 1966).

The interpretation of variations in tree growth requires a constant appreciation of the fact that a living tree responds to many external and internal factors. Fortunately for the analyst, only a few of the environmental factors may exert a major influence on growth. The more pronounced variations in growth may thus be attributable to only one or two factors. Therefore, as Lyon (1936:457) states, "the practical approach to the problem is to notice the responses to extreme values of the factor suspected of being out-

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standing in its control of growth rate."

Growth control may be either direct or indirect or both. However, it is not known how many of these effects are caused directly or indirectly (Kramer 1964). Many interrelated factors (such as temperature, light, evaporation, interception of precipitation by the tree crown, cone production, root distribution, etc.) influence growth. Failure to allow for such contribution factors could lead to erroneous correlations or to none at all.

Finally, it should be pointed out that correlations established between variables over a long period of time are probably more significant than those over relatively short periods of time. The foregoing statement has special relevance when an ephemeral property such as needle length is correlated with annual branch increment or annual ring width. Therefore, a close inspection of needles should be made from year to year and the appropriate data taken. For example, years with heavy cone production show significantly reduced annual ring increment and shoot and needle elongation, even though precipitation is held constant (Tappeiner 1969).

Methods

One mixed stand of Douglas-fir and White Fir was chosen at 2257 m and another at 2500 m. Five trees of each species were sampled at the lower elevation stand and six trees of each species were sampled at the higher elevation site. Sampled trees were healthy, mature individuals. Branches were taken from a height of 1.5–2.5 m above ground on trees sufficiently isolated from one another to receive full light on all sides. Sampled branches were not consistently taken from a given side (i.e., north, south, east, or west) of trees, because Peckham (1973) has shown that leaf parameters for these species do not differ significantly from one side to another on open grown trees.

Ring width samples were taken from cores removed from sample trees with a Swedish increment borer. The cores were taken approximately 1.0 m from the ground. Growth ceases at the base of the tree before it ceases toward the crown (Kramer 1964); thus, the base of the tree will record significant changes in precipitation and provide the most accurate record of macroclimatic variation (Fritts 1966).

Precipitation and temperature data (Table 1) for the period 1 October–30 June of each year of concern were obtained from Utah Climatological Data (1969–1976) for the Santaquin Power House Station some 33 km to the northwest of the study area. The number of days below 0 C for the period March through June were obtained from the Moroni weather station 33 km to the south of the study area (Table 2). Trials demonstrated that Santaquin precipitation and temperature data correlated better with all tree growth parameters than comparable data from Moroni (and better than the average for Santaquin and Moroni precipitation and temperature data). Conversely, Moroni data for days below 0 C correlated better with true growth than similar data from Santaquin. Precipitation and temperature for the period October–December of the preceding year and January–June of the tree growth year under consideration were used for correlation analyses aimed at determining the impact of precipitation on the several measures of tree

TABLE 1. Temperature and precipitation data for the study area at the Santaquin Power House Station during the years 1970–1976.

Year	Average October–June temperature (degrees C)	Average October–June precipitation (cm)
1970	6.3	37.0
1971	6.3	33.9
1972	7.1	33.0
1973	5.4	54.5
1974	7.2	30.1
1975	4.9	37.2
1976	5.9	30.6

TABLE 2. Number of days below 0 C at Moroni for the period March 1–June 30.

Year	Total
1970	65
1971	56
1972	54
1973	66
1974	53
1975	63
1976	60

growth (e.g., 1970 growth variables were paired with October–December 1969 plus January–June 1970 precipitation). Average needle length, average branch length, and average growth ring increment for each year were thus correlated with precipitation and temperature data for that year (offset from calendar year as indicated above). Average needle length was obtained by measuring needles from the beginning, middle, and end of the year's growth on each branch and is reported to the nearest .5 mm, using a Wilde dissection microscope and a millimeter ruler. The annual branch growth was measured between successive terminal bud scars. Average needle retention for each species was also taken.

RESULTS AND DISCUSSION

The growth of Douglas-fir and White Fir differed significantly from year to year between elevations. The greatest average needle growth for Douglas-fir and White Fir was in 1973 at both higher and lower elevations (Tables 3 and 4). This correlates nicely with the fact that the average annual precipitation during the period of record (1970–1976) was highest in 1973. The heavy precipitation of 1973 was associated with normal annual temperature. It is significant that ring width and branch length were also maximal in 1973 for both elevations and species. Radial increases and elongation are directly linked to foliage development (Larson 1964 and Tables 5 and 6).

Average needle length for both Douglas-fir and White Fir were greatest at the lower elevations (Tables 3 and 4). This seems to be in direct contrast to what Peckham (1973) described for Douglas-fir. He found that needle length was greatest at the higher elevations with one exception, although he doesn't elaborate on this exception. Peckham's (1973) findings are reconcilable if one considers that the trees at the lower elevation were experiencing a cold air runoff effect from the higher elevations. However, there are other factors which could effectively bring about the reverse situation of having the longer needles at the lower elevations. These factors might be prolonged snow pack at the higher elevations that might allow the lower elevation trees to get a head start in the growing season.

To examine the effects of temperature on the trees, the number of days during the critical growing season at or below 0 C was measured (Table 2). It appears that freezing temperatures have little discernible effect on annual increment, annual branch length, or needle length (Tables 7 and 8). The possible exception to this might be the year 1975. In that year there was an abnormally large number of days below freezing in the month of May. These freezing temperatures can be implicated in a stunting of the apical meristems and a retardation of growth in 1976. There may have been an integrated effect of climate on food making and food accumulation throughout the 14 to 15 months previous to and including the 1976 period of growth. Therefore, a bad year may exert its effects on the subsequent year's growth (Fritts et al. 1965, Peckham 1973).

The effects of precipitation on the growth rings and branch lengths is indirect (Larson 1964). The needle lengths are directly affected by the amount of moisture and they control the auxins necessary for cambial activity.

TABLE 3. Douglas-fir Measurements at 2257 m above sea level (top) and at 2500 m above sea level (below). Each value is an average based upon five trees at the lower elevation and six trees at the higher elevation.

Year	Ring width increment (mm)	Annual branch growth (mm)	Needle length (mm)
1970	2.9	48.0	26.8
1971	2.9	69.5	35.0
1972	2.6	55.1	29.6
1973	4.3	68.3	35.9
1974	2.5	41.1	28.4
1975	3.6	70.0	29.8
1976	2.7	44.6	31.5
Year	Ring width increment (mm)	Annual branch growth (mm)	Needle length (mm)
1970	1.8	38.1	30.0
1971	1.8	43.8	29.8
1972	1.8	37.6	27.7
1973	2.3	46.0	29.7
1974	1.5	36.6	23.9
1975	2.3	42.0	29.1
1976	1.3	36.6	27.5

Thus, the indirect effect is transmitted via the phloem. However, as previously noted, there is a depletion effect of the hormones the further down the stem one goes. Therefore, one might expect a comparatively less pronounced effect of precipitation in the annual increment than in the annual branch length of the branches. This is demonstrated to be the case. In dry seasons wood formation usually stops quite early in the summer because of water stress, but in wet seasons it may continue until September or October and finally is slowed down and stopped by the processes associated with low temperatures and decreasing photoperiod (Kramer 1964). This fact correlates nicely with growth throughout the tree (Tables 3 and 4).

Correlation among growth variables for both White Fir and Douglas-fir for both elevations are shown in Tables 5 and 6. All growth variables for both species are positively correlated among themselves, but the interrelationships are usually not statistically significant. Thus prediction of one growth variable from another would be risky. Each growth response apparently has a unique relationship to environment. The simple correlations for each growth variable on each environmental variable are reported in Table 7. All growth variables are positively correlated with precipitation, but temperature and days below 0 C usually negatively affected all the growth parameters that were considered.

Multiple correlation coefficients are always larger than any simple correlation coefficient for the relationship between a particular growth parameter and the environment variables considered (Tables 7 and 8). That result strongly suggests that more than one environmental factor has a significant impact on growth. In stepwise multiple regression analyses (Table 8), precipitation usually enters the analysis first; temperature usually follows precipitation in order of entry into the analysis, but its contribution to the (R^2) is generally small. Days below 0 C have their greatest impact on needle length, but even there the impact is weak.

Needle retention data have been reported for Douglas-fir and White Fir. Peckham (1973) reports needle retention in Douglas-fir of 3 or 4 to more than 20 years. Lamb (1969)

TABLE 4. White Fir measurements at 2257 m above sea level (top) and at 2500 m above sea level (below). All values are based on five trees at 2257 m and six trees at 2500 m elevation.

Year	Ring width increment (mm)	Annual branch growth (mm)	Needle length (mm)
1970	2.7	44.7	33.0
1971	3.4	51.0	35.0
1972	2.4	36.6	35.5
1973	3.3	56.7	38.3
1974	2.3	36.7	28.3
1975	3.2	48.4	34.9
1976	2.5	35.1	27.8
Year	Ring width increment (mm)	Annual branch growth (mm)	Needle length (mm)
1970	1.3	45.3	29.0
1971	1.9	44.2	34.0
1972	1.4	44.5	28.4
1973	2.2	49.1	33.6
1974	1.1	39.2	28.6
1975	1.8	39.7	31.8
1976	1.1	35.7	25.7

TABLE 5. Correlation among growth variables at 2257 m.

Variables compared	Correlation coefficient (r)	
	Douglar-fir	White Fir
Ring width-needle length	.54	.69
Ring width-annual branch growth	.71	.96++
Needle length-annual branch growth	.66	.78+

+ = significance at the .05 level
++ = significance at the .01 level

TABLE 6. Correlation among growth variables at 2500 m.

Variables compared	Correlation coefficient (r)	
	Douglar-fir	White Fir
Ring width-needle length	.58	.93++
Ring width-annual branch growth	.79+	.66
Needle length-annual branch growth	.64	.64

+ = significance at the .05 level
++ = significance at the .01 level

reports needle retention in White Fir to be from 12 to 20 years. There was no significant trend in years of retention at varying elevations in either study. Table 9 shows needle retention for Douglas-fir and White Fir. Our data show Douglas-fir to retain needles about 9 years at low elevations and 6 years at higher elevations. White fir holds needles 8–9 years at both elevations.

Considering all the above data, it is difficult to say which of the trees is responding more closely to the environment and at what elevation. White Fir has a range in elevation between 1833–3850 m and Douglas-fir grows from sea level to timberline (Cronquist et al. 1972). Needle retention for White Fir is greater than for Douglas-fir at 2500 m; the situation is reversed at 2257 m (Table 5). Although the sample size is somewhat less than one needs to draw conclusions, the results may indicate that White Fir is better adapted at the higher elevation in our study area.

Douglas-fir and White Fir at both elevations are very similar with respect to annual ring width increment and needle length. However, there is great disparity in the lengths of the branches between the two species. At 2257 m the branches on Douglas-fir are visibly longer than those on White Fir, and at 2500 m White Fir has the longer branches (Tables 3–4). There seems to be a similar trend here (as in needle retention) for White Fir to respond more favorably then Douglas-fir at the higher elevation, but for Douglas-fir to respond more favorably at the lower elevation.

Conclusions

Environment plays a decisive role in tree growth through its effect on annual increment, annual branch length, and needle length. Nevertheless, the effect of the environment is considered to be primarily indirect. Environment induces either temporary fluctuations or long-term modifications on growth.

Considerable annual variation occurred in needle length and branch length and to a lesser degree in annual ring width increment. Optimum growth for the above three criteria is shown to be related to elevation and annual precipitation.

The data contained in this report will be useful in determining normal macroenvironmental growth patterns and variations for the tree species studied. This information would be useful in determining the local effects of air pollutants and/or climatic variations in the future.

One of the purposes of this study was to test an in-the-field method for determining year-to-year growth variation for two conifer tree species. It is our opinion that this type of evaluation could be done most accurately by inspection of the annual ring width increment and secondarily with annual branch lengths. The field observer is also encouraged to pay close attention to cone production of the trees, as it will have a marked effect on all aspects of growth.

We suggest that White Fir and Douglas-fir respond differently to environment as modi-

Table 7. Correlations between various independent and dependent variables for Douglas fir and White Fir at two elevations.

Independent variables	Douglas-fir Ring width	Douglas-fir Branch growth	Douglas-fir Needle length	White Fir Ring width	White Fir Branch growth	White Fir Needle length
	Elevation 2257 m					
	Simple correlation coefficient					
Precipitation (log)	.94++	.60	.52	.63	.83+	77+
Temperature	–.79+	–.63	–.38	–.70	–.63	–.38
Days below 0 C	–.23	–.01	–.17	–.36	–.33	.33
	Elevation 2500 m					
Precipitation (log)	.80+	.79+	.58	.80	.75+	.64
Temperature	–.64	–.61	–.60	–.60	–.03	–.42
Days below 0 C	.05	–.24	–.02	–.09	+.25	–.23

+ = significance at the .05 level
++ = significance at the .01 level

Table 8. Stepwise multiple regression results for the effects of October–June precipitation, average October–June temperature, and days below 0 C for the period March–June on three growth parameters. Results are given for Douglas-fir and White Fir at two elevations.

Elevation 2257 m

Independent variable	Douglar-fir	White Fir
Ring width		
	Contributions to R^2	
Precipitation (log)	.88	.08
Temperature	.09	.49
Days below 0 C	.00	.02
Total R^2	.97++	.59
Branch length		
Precipitation (log)	.08	.69
Temperature	.40	.01
Days below 0 C	.05	.07
Total R^2	.53	.77
Needle length		
Precipitation (log)	.27	.59
Temperature	.00	.01
Days below 0 C	.02	.15
Total R^2	.29	.75

Elevation 2500 m

Independent variable	Douglar-fir	White Fir
Precipitation (log)	.64	.65
Temperature	.05	.03
Days below 0 C	.05	.00
Total R^2	.74	.68
Branch length		
Precipitation (log)	.62	.57
Temperature	.04	.24
Days below 0 C	.01	.01
Total R^2	.67	.82
Needle length		
Precipitation (log)	.41	.08
Temperature	.00	.36
Days below 0 C	.03	.04
Total R^2	.44	.48

++ = significance at the .01 level

Table 9. Needle retention by altitude for:

Douglas-fir

Altitude (m)	Sample size	Years of needle retention
2257	138	9.2
2500	102	5.7

White Fir

Altitude (m)	Sample size	Years of needle retention
2257	123	8.2
2500	159	8.8

fied by elevation in respect to annual ring width increment and branch lengths.

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